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Physiological determinants of cowpea seed yield as affected by phosphorus fertilizer and sowing dates in intercrop with millet

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Abstract

The interaction of cowpea (*Vigna unguiculata* (L.) Walp.) cultivars with management factors and environments was analyzed in terms of parameters of a simple physiological model. In one set of experiments seven cultivars were sown at three rates of phosphorus (P) fertilizer (0, 8 and 16 kg P ha^{-1}). In another set, five cultivars were sown on two dates relative to sowing of millet (*Pennisetum glaucum* (L.) R.Br.). All experiments involved factorial combinations of management and cultivar treatments, and were conducted in 1988 and 1989 at two sites in western Niger. Seed yield, shoot dry matter, vegetative (D_v) and reproductive (D_r) durations were determined and crop growth rate (C) and partitioning (p) to seed estimated.

Application of P increased seed yield by increasing C. As sowing was delayed from 1 to 3 weeks after the millet was sown, there was a reduction in seed yield due to decreases in C, D_v and D_r. Variation in cultivar performance across years was mainly a function of C and partitioning. In both experiments the C of the landrace Sadore Local was greater than that of other cultivars, although the partitioning to seed of this cultivar was unstable due to variable control of insect pest damage.

It is concluded that the primary causes of G×E interactions were differential canopy development and insect damage effects. Therefore in the development of cowpea cultivars for intercropping with millet, emphasis should focus on light capture capabilities. Improved yields would then seem possible with most cultivars, providing insect damage is controlled.

Key words: Cowpea; Intercropping; Millet; *Pennisetum*; Phosphorus; Sowing date; *Vigna*; Yield determination

1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) forms an integral part of the cropping systems in the semi-arid tropics of west Africa where it is usually grown in association with cereals. A wide range of seed yields have been recorded for cowpeas but are generally less than 100 kg ha^{-1} in traditional systems. Among the factors responsible for the low yield are low soil fertility, untimely cultural operations and the numerous insect pests (Ntare et al., 1989).

Many plant traits are associated with seed yield and various approaches have been used to explain seed yield as a function of these (Kwapata and Hall, 1990; Ntare, 1992). Numerous estimates of correlations between yield and other traits in cowpea are also available (Imrie and Butler, 1983; Ntare, 1992). In cereal crops, crop growth rate and partitioning contribute to grain yield (Donald and Hamblin, 1976), and in grain legumes the role of these traits in determining seed yield have been demonstrated in soybeans and groundnuts (McWilliams and Dillon, 1987).

Studies have been conducted on various agronomic factors that affect cowpea yield in intercropping with millet. These include plant types (Ntare, 1989; Reddy et al., 1990), effect of fertilizers (Fussell and Serafini, 1985; Ntare and Bationo, 1992), sowing dates of cowpea relative to millet (Ntare and Williams, 1992) and

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effect of cropping systems (Reddy et al., 1992). None of these studies, however, considered the influence of these management practices on the physiological determinants of seed yield and their interrelationships. Such information can be used to suggest strategies which might be useful in planning further research and in guiding selection of cultivars suitable for intercropping with millet.

For indeterminate crops Duncan et al. (1978) proposed that yield differences could be analyzed using the model:

$$Y = C^* d^* p \quad (1)$$

where Y is the yield of fruits or seeds, C is the mean crop growth rate, d is the duration of the reproductive growth and p is the mean fraction of crop growth rate partitioned towards reproductive sinks. The C and p components of the model are often determined through growth analysis based on destructive sampling. Williams and Saxena (1991) demonstrated that these parameters can also be estimated from final harvest data and phenological observation without extensive destructive measurements. While the model is simple, and caution needs to be exercised in its use, it allows interpretation of agronomic data in a more mechanistic manner than is possible from original data.

Our objective was to use this non-destructive approach to increase understanding of the effects of agronomic management factors on the determination of seed yield in an intercrop situation.

2. Materials and methods

Two field experiments were conducted in a Psammentic Paleustalf in south western Niger in 1988 and 1989. Details of experimental designs, plot size and agronomic practices have been described previously (Ntare and Bationo, 1992; Ntare and Williams, 1992) and only the salient features are repeated here.

Millet was sown in hills in five rows 6.75 m long. Hills were 0.75 m apart within a row and 1.50 m between rows. Cowpea was sown between millet rows with a similar spatial arrangement to that of the millet. These densities were slightly higher than the traditional practice and result in higher yields. For both crops, excess seeds were sown per hill to allow thinning to three plants per hill.

Rainfall received at Sadore from June to September was 699 mm in 1988 and 623 mm in 1989. This was 25 and 11%, respectively above the long-term average (90 years) of 560 mm for Niamey. In 1988, the rainfall was well distributed but not in 1989 during the growing season. June rainfall was 41% below the long-term average and July rainfall 36% below. There was a dry spell of 15 days in July during the vegetative phase of cowpea and plant moisture stress was evident. Moisture availability was good in August and September during flowering and podding. The rainfall received at Goberi was 749 mm in 1988 and 424 mm in 1989. The distribution showed similar trends to that at Sadore.

The cowpea was sprayed at flowering and pod-filling stages to control insect pests. No supplementary irrigation was given.

2.1. Experiment 1: Effect of P rates

This experiment was conducted in farmers' fields both near the ICRISAT Sahelian Center (ISC) research farm at Sadore, 43 km south of Niamey and Goberi, 120 km east of Niamey. The treatments were in a split-plot arrangement in a randomized complete block design with four replications. The P rates (0, 8, and 16 kg ha^{-1}) were the main plots and seven cultivars were sub-plots. The cultivars were: TVX4659–03E, an erect indeterminate cultivar from hybridization; TN88–63, TN5–78 and Dan Illa, purified landraces commonly grown in Niger; Suvita 2, a purified landrace commonly grown in the Sahelian zone of Burkina Faso; and two unpurified landraces, Tera Local and Sadore Local from Niger. Sadore Local is sensitive to photoperiod and late maturing (>90 days). The other cultivars are relatively photoperiod insensitive and of medium maturity (75 days).

2.2. Experiment 2: Effect of sowing date

This experiment was conducted at the ISC research farm and in a farmer's field at Goberi. Five cowpea cultivars were sown at two sowing dates in relation to the millet sowing date. Five cultivars, TVX3236 (semi-erect with profuse flowering habit and maturing in 70 days), B111–2 (semi-spreading type maturing in 65 days), Suvita 2, TN5–78 and Sadore Local were sown at two dates relative to the millet sowing date. The cultivars TVX3236 and B111–2 are the product of deliberate hybridization and selection. The planned sowing dates for the cowpea were 1 week and 3 weeks after the sowing of millet.

In all the experiments, plants were harvested at soil level and recoverable senesced leaves collected. The samples were air dried to constant weight and shoot dry matter and grain yield determined. The crop growth rate and partitioning coefficients were estimated according to Williams and Saxena (1991):

$$C=(V+Y)/(D_v+D_r) \quad (2)$$

$$p=(Y/D_r)/C \quad (3)$$

Table 1
Summary of main effects on seed yield (kg ha^{-1}), crop growth rate C (kg ha^{-1} day^{-1}), partitioning (p), vegetative duration (D_v) in days, and reproductive duration (D_r) in days in experiment 1

Location	Main effects	Seed yield	C	p	D_v	D_r
Sadore	*Year*					
	1988	200	16.0	0.59	59	24
	1989	70	5.3	0.62	53	19
	P rate (kg ha^{-1})					
	0	100	8.3	0.56	57	21
	8	140	10.3	0.65	56	22
	16	160	13.4	0.60	55	21
	Cultivars					
	TVX4659-03E	95	10.1	0.39	53	20
	TN5-78	190	11.9	0.74	54	21
	Dan Illa	140	8.7	0.76	54	21
	Suvita 2	140	8.4	0.73	54	21
	TN88-63	170	10.5	0.68	57	21
	Tera Local	130	10.2	0.57	54	22
	Sadore Local	80	14.9	0.37	66	23
Goberi	*Year*					
	1988	250	17.9	0.56	54	26
	1989	60	5.0	0.47	54	22
	P rate (kg ha^{-1})					
	0	110	7.1	0.47	54	24
	8	150	10.9	0.50	54	24
	16	215	15.6	0.56	54	24
	Cultivars					
	TVX4659-03E	95	12.1	0.30	47	23
	TN5-78	175	12.7	0.54	51	22
	Dan Illa	120	7.2	0.62	52	23
	Suvita 2	120	7.2	0.56	52	24
	TN88-63	160	9.6	0.57	55	24
	Tera Local	140	12.7	0.43	50	22
	Sadore Local	290	18.4	0.57	68	27
	Significance					
	Year (Y)	**	**	NS	**	**
	Location (L)	**	NS	**	**	**
	P rate (P)	**	**	**	**	NS
	Cultivars (C)	**	**	**	**	**
	Y×L	**	*	**	**	NS
	Y×P	**	**	**	**	NS
	Y×C	**	**	**	**	**
	L×P	**	*	**	**	**
	L×C	**	*	**	**	**
	P×C	NS	NS	NS	NS	NS
	Y×L×P×C	NS	NS	NS	NS	NS

*, **, significant at 0.05, 0.01 probability levels, respectively.
NS = not significant at 0.05 level.

Table 2
Summary of main effects on seed yield (kg ha^{-1}), crop growth rate C (kg ha^{-1} day^{-1}), partitioning (p), vegetative duration (D_v) in days, and reproductive duration (D_r) in days in experiment 2

Location	Main effects	Seed yield	C	p	D_v	D_r
Sadore	*Year*					
	1988	150	11.0	0.57	59	30
	1989	250	11.8	1.51	54	19
	Cultivars					
	TVX3236	50	3.1	0.98	52	24
	B111-2	150	8.3	1.07	55	23
	Suvita 2	270	12.7	1.21	52	26
	TN5-78	270	13.7	1.15	54	25
	Sadore Local	250	19.2	0.80	70	26
	Sowing date					
	1 week delay	260	17.1	1.16	56	26
	3 weeks delay	100	5.7	0.93	48	24
Goberi	*Year*					
	1988	220	10.7	0.88	45	26
	1989	170	8.9	0.97	54	24
	Cultivars					
	TVX3236	50	2.9	0.82	46	24
	B111-2	110	7.2	0.80	44	24
	Suvita 2	170	9.3	0.97	46	24
	TN5-78	180	9.7	1.00	46	24
	Sadore local	450	19.9	1.06	65	30
	Sowing date					
	1 week delay	310	13.0	0.99	57	26
	3 weeks delay	100	6.6	0.87	50	24
	Significance					
	Year (Y)	**	NS	**	**	**
	Location (L)	NS	**	**	**	NS
	Cultivars (C)	**	**	**	**	**
	Sowing date (D)	**	**	**	**	**
	Y×L	**	**	**	**	**
	Y×C	**	**	**	**	**
	Y×D	**	NS	NS	NS	NS
	L×C	**	**	**	**	**
	L×D	**	**	NS	NS	NS
	C×D	**	**	**	**	NS
	Y×L×C×D	**	NS	NS	NS	NS

*, **, significant at 0.05, 0.01 probability levels, respectively.
NS = not significant at 0.05.

where V = total vegetative mass (including fallen leaves), D_r = duration from flowering to maturity, D_v = duration from sowing to start of flowering, and Y = seed yield.

Each combination of year, site and management treatment (P application or sowing date) was defined as an environment in which the model parameters for each variety were regressed against the mean of all cultivars as an environmental index (Finlay and Wilkinson, 1963). In experiment 1 this approach defined 12 environments, while experiment 2 provided 8 environments.

3. Results

3.1. Phenology and seed yield

Phenology was on average not influenced by P application, but the reproductive duration was shorter in 1989 than in 1988 (Table 1). Seed yields were greater

Table 3
Correlation matrix between grain yield and growth parameters in experiment 1 and 2 in 1988 (below diagonal) and 1989 (above diagonal)

Experiment	Parameters	Grain	D_v	D_r	C	p
1	Grain	–	0.90	0.69	0.98	0.15
	D_v	0.02	–	0.85	0.93	−0.06
	D_r	0.13	0.12	–	0.78	−0.48
	C	0.63	0.14	−0.03	–	−0.02
	p	0.40	−0.14	−0.18	−0.32	–
2	Grain	–	0.44	0.32	0.92	0.61
	D_v	0.60	–	0.51	0.41	−0.01
	D_r	0.61	0.46	–	0.32	−0.19
	C	0.93	0.75	0.52	–	−0.38
	p	0.51	0.19	0.37	0.29	–

Experiment 1, $N=168$ and experiment 2, $N=10$.

Table 4
Regression parameters (b_i, R^2) for the relationship of cultivar crop growth rate (C) and partitioning (P) on mean crop growth rate and partitioning

Cultivars	Crop growth rate			Partitioning		
	b_i	±s.e.	R^2	b_i	±s.e.	R^2
Experiment 1						
TVX 4659-03E	1.15	0.081	0.95	0.63	0.272	0.35
TN5-78	1.29**	0.098	0.95	1.69**	0.257	0.81
Dan Illa	0.62**	0.059	0.92	0.82	0.230	0.56
Suvita 2	0.59**	0.068	0.88	1.30	0.304	0.65
TN88-63	0.87	0.124	0.83	1.07	0.510	0.31
Tera Local	1.29*	0.110	0.93	1.26	0.256	0.71
Sadore Local	1.19	0.120	0.91	0.23	0.983	0.00
Experiment 2						
TVX 3236	0.19**	0.048	0.71	0.57*	0.189	0.60
B111-2	0.63**	0.102	0.86	1.19	0.135	0.92
Suvita 2	1.21	0.070	0.98	1.21	0.144	0.93
TN5-78	1.22	0.174	0.89	0.99	0.202	0.80
Sadore Local	1.75**	0.337	0.82	1.15	0.413	0.57

*, **significantly different from 1.0 at 0.05 and 0.01 probability levels.

in 1988 than in 1989 at all P rates. Seed yield increased by 60% with the addition of 16 kg P ha^{-1} at Sadore and 95% at Goberi. Crop growth increased nearly two-fold with application of P. Partitioning was on average little affected by P. Strong main effects of year, P rates and cultivar, and highly significant interactions for a combination of factors occurred for most of the variables.

As sowing was delayed from 1 week to 3 weeks, there was a decrease in all variables (Table 2). There was a 7-day decrease in the average vegetative and 3-day decrease in reproductive duration. Thus crop dura-

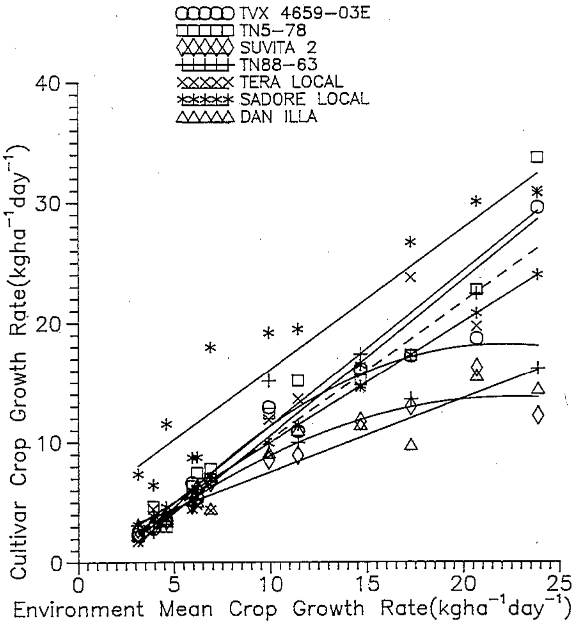

Fig. 1. Crop growth rate (C) of seven cowpea cultivars regressed against environmental means with unity regression (- - -) in experiment 1.

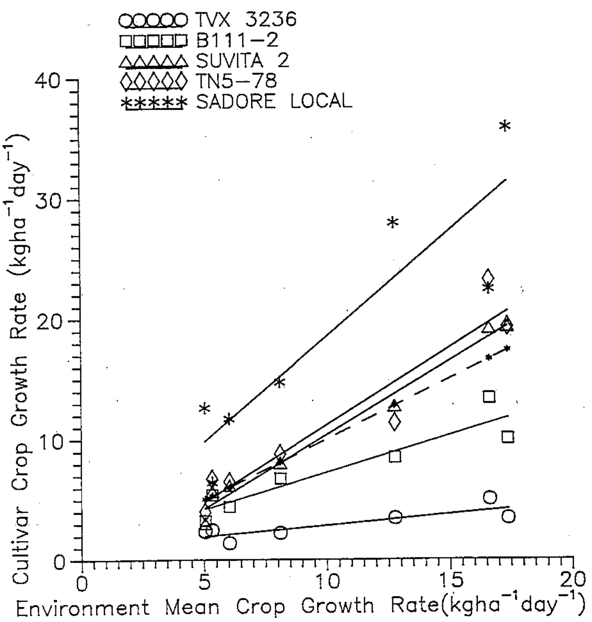

Fig. 2. Crop growth rate (C) of five cowpea cultivars regressed against environmental means and unity regression (- - -) in experiment 2.

tion was reduced on average by 10 days in the second sowing date, crops maturing at nearly the same time despite the differences in sowing date. Sowing date significantly ($P<0.01$) affected seed yield. Reduction in seed yield for sowing 3 weeks later compared to 1 week after millet was 61% at Sadore and 68% at Goberi. There was a significant cultivar × sowing date interaction for all variables except reproductive duration (Table 2).

3.2. Crop growth rate and partitioning

Correlations between seed yield and the physiological model parameters show that much of the yield variation was associated with variations in C (Table 3). The differential response in C of cultivars to environments (as characterized by mean C and indicated by the range of b_i values (Table 4)) was consistent. The C of Sadore Local was above average in all environments while Dan Illa and Suvita 2, which had similar C, were below average in all environments (Fig. 1).

As in the P rate series, C of Sadore Local was above average in all environments but was more responsive to better environments, contributing to the cultivar × sowing date interaction (Fig. 2). The two cultivars from breeding, TVX3236 and B111-2, were below average in C, particularly so in the environments more favorable to growth.

On average, partitioning was little changed with the addition of P, and no P rate × cultivar interactions were observed (Table 1). However, there was a strong year × cultivar interaction for this trait associated with the failure of Sadore Local to produce seed at Sadore in 1988. The response of partitioning to environments was less variable than C except for Sadore Local which had very erratic partitioning (Table 4).

4. Discussion

It should be remembered throughout the discussion that this paper focuses on only one component of the intercrop. The correlation matrices between seed yield and the model parameters show the dominance of C as a source of yield variations. Since C is determined by light interception and a conservative light-use efficiency, C can be taken as a surrogate for light interception.

The effect of the 1989 environment compared to 1988 was to decrease seed yield and crop growth rate in the two experiments reflecting the poorer water relations in that year. Given the comparatively wide spacing used in intercropping, the phenological potential of the cultivars in the two experiments was inadequate to result in closed canopies, particularly in 1989, when plants experienced moisture stress during the vegetative growth in addition to competition from millet (Ntare and Williams, 1992).

Phosphorus rates and sowing dates were responsible for substantial variation in *C* and seed yield within cultivars. In the best environments, *C* of the best cultivar was only some 10% of the maximum recorded for C_3 species, indicating the reduction in either available resources, or their capture. What cannot be established from these data is the amount of light that was available to cowpea intercrop after interception by millet, but it is significant that higher P levels resulted in higher *C* despite the increased millet growth (and concomitant decrease in radiation available to the cowpea) in response to that fertilizer. There were considerable variations in the *C* response of cultivars to these variations in environment. In the poorest *C* environments all cultivars were similar excepting Sadore Local which was consistently superior to other cultivars across all the environments. As the environment improved the differences between cultivars increased.

Most cultivars showed a linear response, but TN88-63 and Suvita 2 were not able to increase their *C* at the same rate as the others as the environment improved (Fig. 1). These differences probably reflect the effect of canopy architecture and phenology on the light interception and point to the potential to use genetic options to maximize *C*. Although plant stand manipulations could compensate for canopy development characteristics of a given cultivar, this may require additional resources (e.g. labor and seed). This points to an important aspect of the interpretation of agronomy trials involving different cultivars. Often trial management uses standard populations on the assumption that this will not confound the results. The method we used allows this assumption to be checked, and provides a good reason for using a model-based growth analysis in trials (Williams and Saxena, 1991).

The role of competition in determining the light available to the cowpea crop is reflected in the effects of sowing dates relative to the millet. Sowing late resulted in a *C* which was approximately half of that of the earlier sowing. It seems likely that photoperiod effects contributed to this by influencing the time available for canopy development.

Partitioning varied moderately with the "environmental" factors, but most cultivars had stable partitioning in this range of environments. The unstable partitioning of Sadore Local was attributed mostly to failure to control insect pests. In these trials the early flowering cultivars were sprayed at a time when Sadore Local had not reached the most sensitive stage to insect damage and this could be an important cause of G×E interaction. However, despite its long duration, there was comparable partitioning to seeds by this cultivar once insects were controlled. This suggest that water was not a limiting factor during the grain growth phase, even for the latest maturing cultivar.

The successful development of cowpea cultivars for intercrop use in the Sahel requires development of cultivars better adapted to the poor soil fertility. Sadore Local seems to have some advantage in this regard since it had distinctly better *C* in the poorest environment. However, it remains to be seen what optimizing population may achieve for the other cultivars.

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